Atelectasis will generally show signs of diminished lung volume, while pneumonia causes increased volume.

**Pneumonia versus atelectasis—enhancement characteristics.**
Atelectasis shows intense homogeneous enhancement (posterior) contrasting with the slight, inhomogeneous enhancement of the infiltrate (anterior).

**Fig. 2.76**

Pneumothorax

Pneumothorax is a relatively common and important finding in the ICU, especially in ventilated patients. Pneumothorax may have an iatrogenic cause in ICU patients and may result from surgery, barotrauma, or catheter-related complications (Table 2.38). Rare causes of pneumothorax are blunt or penetrating thoracic trauma and mediastinal emphysema with the secondary development of a pneumothorax.

A pneumothorax may develop hours or even days after successful (or unsuccessful) pleural drainage. It may also result from suboptimal placement of a thoracostomy tube.

### Table 2.38 Causes of pneumothorax in ICU patients

<table>
<thead>
<tr>
<th>Iatrogenic (common):</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Barotrauma</td>
</tr>
<tr>
<td>- Central venous catheter</td>
</tr>
<tr>
<td>- Thoracentesis, thoracostomy</td>
</tr>
<tr>
<td>- Cardiac massage</td>
</tr>
<tr>
<td>Blunt or penetrating thoracic trauma (rare):</td>
</tr>
<tr>
<td>- Mediastinal emphysema with secondary pneumothorax</td>
</tr>
<tr>
<td>- Tracheobronchial injuries</td>
</tr>
<tr>
<td>- Tracheotomy</td>
</tr>
<tr>
<td>- Barotrauma</td>
</tr>
<tr>
<td>- Tracheal or esophageal perforation</td>
</tr>
</tbody>
</table>

**Treatment.** An acute pneumothorax (without septations) can be drained through an 8–10F catheter which is usually placed in the second intercostal space in the midclavicular line (anterior) or in the sixth to eighth intercostal space in the midaxillary line. With a loculated pneumothorax, the drains should be placed under CT or ultrasound guidance.

**Diagnostic Strategy**

The method of first choice is the portable chest radiograph. If the frontal view does not yield a clear diagnosis, other options are to obtain a lateral chest radiograph (difficult to position), a lateral decubitus view, or a tangential view.

The most rewarding imaging modality in patients with clinical suspicion of an occult pneumothorax is computed tomography.

Increasingly, ultrasonography is being used as a bedside study for the diagnosis of pneumothorax.
Imaging

Radiography and Computed Tomography

Localization. In the supine patient, the classic signs of pneumothorax are seen only with a relatively large intrapleural air collection and a compliant lung (Fig. 2.77). Air in the supine patient tends to be distributed in the anterior and basal portions of the pleural space (Table 2.39). Sites of predilection in supine patients are anteromedial and subpulmonic (Fig. 2.78). Anterior air collections on the AP chest radiograph may easily escape direct detection. Watch for these signs:
- a sharp diaphragm silhouette
- a rounded or oval-shaped area of increased lucency (“black oval”)
- an avascular area

Volume estimation. The extent of a pneumothorax is difficult to estimate on portable chest radiographs. Suction

---

Fig. 2.77 Pneumothorax.
The classic radiographic signs of pneumothorax are seen only with a large air collection and a compliant lung.

Fig. 2.78 a–c  Anterior or anterobasal pneumothorax.
An anterior or anterobasal pneumothorax is often manifested only indirectly by a rounded hyperlucent area with well-defined margins (a), an avascular area (b), or sharp outlining of the cardiac borders or diaphragm (c).
Drainage is indicated if more than 35% of the lung volume is affected. The indication for drainage depends on clinical manifestations, a visual volume assessment on the chest radiograph, and on tension signs.

Choi et al. (1998) described a formula for estimating the volume of a pneumothorax. The average interpleural distances are measured at apical, lateral, and laterobasal locations and are used in the following formula:

\[
\frac{(a + b + c)}{3} \times 10 + 9 = \text{percentage pneumothorax size}
\]

One limitation of this formula is that the pneumothorax must extend along the lateral chest wall and must be defined there. We know from experience, however, that the anterior pneumothorax in supine patients may reach a considerable size without displaying clear outlines, resulting in a gross underestimation of pneumothorax size on the chest film (Fig. 2.80). If radiographic findings are equivocal, CT should be used for the detection, localization, and quantification of pneumothorax, even in preparation for chest tube placement.

**Barotrauma.** The detection or exclusion of pneumothorax may be difficult or impossible when subcutaneous empyema (e.g., due to barotrauma) is superimposed on the

### Table 2.39 Location and radiographic signs of pneumothorax in the supine patient

| Location                  | Indirect signs of pneumothorax                                      |
|---------------------------|====================================================================|
| Anteromedial pneumothorax | **Suprahilar**                                                      |
|                           | ▪ Sharp outlining of:                                               |
|                           |   – superior vena cava                                             |
|                           |   – azygos vein                                                    |
|                           |   – left subclavian artery                                          |
|                           |   – superior pulmonary vein                                        |
|                           | ▪ Contralateral displacement of anterior pleural reflection         |
| Infrahilar                 | ▪ Sharp outlining of:                                               |
|                           |   – cardiac border                                                 |
|                           |   – inferior vena cava                                             |
|                           |   – cardiophrenic angle                                            |
|                           |   – medial part of diaphragm below cardiac silhouette              |
|                           |   – pericardial fat pad                                            |
| Subpulmonic pneumothorax  | ▪ Hyperlucent upper quadrant                                       |
| (chest radiograph must    | ▪ Deep costophrenic sulcus (deep sulcus sign)                      |
| include the upper abdomen)| ▪ Sharp outlining of the diaphragm                                 |
|                           | ▪ Appearance of a second diaphragm shadow ("double diaphragm sign")|
|                           | ▪ Delineation of inferior vena cava                                |
| "Classic" apicolateral    | ▪ Lack of contact between the minor fissure and chest wall         |
| pneumothorax              |                                                                   |

**Fig. 2.79** Estimation of pneumothorax size using the formula of Choi et al. (1998).

**Fig. 2.80 a, b** Gross underestimation of pneumothorax size in the supine radiograph.
Chest radiograph (a) and CT scan (b) of the same patient taken 2 hours apart.
radiograph (Fig. 2.81), and CT may be appropriate in these cases. Premonitory signs of barotrauma are interstitial emphysema after the rupture of interstitial septa, which may be followed by air dissection to the mediastinum (mediastinal emphysema) and into the soft tissues (soft-tissue emphysema; see p. 46).

The risk of pneumothorax in barotrauma is significantly increased when the hemidiaphragm is lower than the sixth anterior rib segment or when the craniocaudal extent of the lung is greater than 25 cm.

**Ultrasonography**

In the absence of pneumothorax, the ultrasound scan shows lung sliding along the echogenic pleural interface during inspiration and expiration. It also shows comet tail artifacts, which are high-level reverberations extending from the pleural line to the lower edge of the screen (Fig. 2.82). With pneumothorax, both criteria are absent because of air in the pleural space. The absence of lung sliding during respiration is considered to have a negative predictive value of 90–100% and a false-positive rate of 10%.

Ultrasonography can be a useful diagnostic aid in bed-confined patients with equivocal radiographic findings.

**Differential Diagnosis**

**Skin folds.** Mistaking skin folds for pneumothorax on chest radiographs is most likely to occur in elderly and cachectic patients. Skin folds typically extend beyond the chest wall, are often multiple or bilateral, disappear suddenly, and are traversed by vascular structures (Fig. 2.83). Other signs of skin folds are indistinct margins, an associated soft-tissue shadow, and nonparallel alignment relative to the chest wall. Skin folds are easy to recognize as a rule, and only rarely do they require repeating the chest radiograph under controlled conditions or proceeding with CT.

**Other air collections.** The following intra- and extrathoracic air collections may not be misinterpreted as pneumothorax: lung cysts, emphysematous bullae, pneumatoceles, air collections in the mediastinum, pericardium or thoracic soft tissues, intrathoracic hernias (Fig. 2.84).
Acute Gastrointestinal Bleeding

Acute gastrointestinal (GI) bleeding is still associated with a high morbidity and mortality (from 20 to 40%, depending on the severity of the bleeding and hemodynamic instability).

The radiologic detection of GI bleeding (by selective angiography or CT angiography) requires continuous, active bleeding at a rate greater than 0.5 mL/min. It should be noted, however, that bleedings are often intermittent rather than continuous. This explains the frequent paradox of negative CT or angiographic findings in a patient with impressive clinical signs of active or prior hemorrhage (melena, etc.).

Pathogenesis

Upper GI bleeding. By definition, upper GI bleeding originates proximal to the ligament of Treitz, that is, in the esophagus, stomach, or duodenum. Upper GI bleeding is approximately twice as common as bleeding in the lower GI tract and occurs predominantly in younger patients. The most frequent causes of upper GI bleeding are ulcer hemorrhage and bleeding esophageal varices (up to 50% mortality) (Table 4.8). Symptoms of acute upper GI bleeding in ICU patients should always raise suspicion of an acute ulcer hemorrhage, even in patients on medication for ulcer prophylaxis.

Endoscopy is the primary tool for the diagnosis of upper GI bleeding, although it cannot identify a bleeding source in up to 20% of cases, even with massive bleeding (> 1 mL/min). Peritonitis and sepsis due to an untreated perforated ulcer develop within 6 hours in 5% of cases, within 24 hours in 40% of cases, and have a high mortality.

Lower GI bleeding. Lower GI bleeding may originate in the small bowel, colon, or rectum. It is less common than upper GI bleeding and occurs predominantly in older patients. The most frequent causes are diverticulitis and angiodysplasia (Table 4.9). There is controversy as to whether invasive angiography or CT angiography is better for evaluating lower GI bleeding. The method of choice will depend on individual patient status and the severity of the bleeding.

Intramural small bowel bleeding. These Bleeds most commonly result from coagulation disorders. Besides anticoagulant therapy, significant causes include coagulopathies secondary to liver disease, lytic therapy, hemophilia, and thrombocytopenia.

Bowel ischemia increases intestinal permeability, leading also to submucous hemorrhage and edema. The cause may be a complicated obstruction (strangulation, incarceration) or mesenteric ischemia (arterial or venous).

Diagnostic Strategy

Endoscopy

Endoscopy is the method of choice for the diagnosis of upper GI bleeding in most cases. It plays a minor role in the acute evaluation of lower GI bleeding, although it is not uncommon for physicians to order endoscopy as the initial examination.

Computed Tomography

Multislice scanners have revolutionized the role of CT angiography in the primary localization of bleeding in both the upper and lower GI tract. One reason for this is that CT appears to be more sensitive than angiography for detecting bleeding at rates below the angiographic threshold of 0.5 mL/min (as low as 0.3 mL/min based on published data).

Another reason for the superiority of CT is its ability to discriminate the cause of the bleeding (tumor vs. diverticulum vs. angiodysplasia) and detect complications that may require immediate surgical intervention (e.g., perforation or large hematoma). Interventionalists value the ability of CT to demonstrate possible anomalies of vascular anatomy and localize the bleeding site, so that the interventional procedure can be planned and performed more efficiently.

Table 4.8 Causes of upper gastrointestinal bleeding

<table>
<thead>
<tr>
<th>Cause</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastroduodenal ulcer</td>
<td>50–70%</td>
</tr>
<tr>
<td>Bleeding gastroesophageal varices</td>
<td>15%</td>
</tr>
<tr>
<td>Mallory–Weiss tears</td>
<td>7%</td>
</tr>
<tr>
<td>Gastric carcinoma</td>
<td>3%</td>
</tr>
<tr>
<td>Paraeosophageal hernia, reflux esophagitis</td>
<td>10%</td>
</tr>
</tbody>
</table>

Table 4.9 Causes of lower gastrointestinal bleeding

<table>
<thead>
<tr>
<th>Cause</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverticulitis</td>
<td>Up to 50%</td>
</tr>
<tr>
<td>Angiodysplasia</td>
<td>Up to 40%</td>
</tr>
<tr>
<td>Neoplasm</td>
<td>26%</td>
</tr>
<tr>
<td>Colitis</td>
<td>20%</td>
</tr>
<tr>
<td>Anorectal lesions, hemorrhoids</td>
<td>10%</td>
</tr>
</tbody>
</table>
Technique. When intra-abdominal bleeding is suspected, an initial noncontrast series should be obtained to distinguish a fresh extravasation from intraintestinal thrombi or hyperdense structures due to other causes (e.g., oral contrast residues) and enhancing lesions. The subsequent contrast series (120–140 mL at 3.5–4 mL/s, 370–400 mg iodine/mL) can be acquired during the arterial perfusion phase (ca. 10-s delay after the aortic peak of 150 HU) or the late arterial phase (25 s after the aortic peak). The advantage of scanning in the late arterial phase is that it is more sensitive to slower bleeds and provides good visualization of even the small peripheral mesenteric branches. A second scan performed during the portal venous phase (70–75 s) can detect venous extravasation, aid in defining possible neoplastic causes of hemorrhage, and assess bleeding activity by measuring the density and increasing size of the extravasate (pooling or arterial blush) (Fig. 4.24, see also Fig. 4.28). Sometimes the source is easily identified based on obvious vascular pathology (e.g., postinflammatory aneurysm or pseudoaneurysm) (Fig. 4.25). Attention should also be given to indirect signs such as bowel wall thickening due to intramural hemorrhage, extraintestinal hematoma formation, and intraluminal thrombi (Fig. 4.26).

--- Practical Recommendation
Comparison of precontrast and postcontrast CT scans has proven to be a more sensitive technique than looking for a focus with >90 HU attenuation, as some authors have recommended. It is important to distinguish between extravasation and mucosal enhancement; this can be particularly difficult in collapsed bowel (Fig. 4.27). It is helpful in these cases to take an additional scan after the arterial phase and check for increased enhancement (blush) on the delayed scan (see Fig. 4.24). Significant bleeding is almost always detectable, however, by comparing the plain and contrast-enhanced series and by evaluating enhancement dynamics (increasing enhancement) between the arterial and portal venous phases.
Complications

Gastrectomy is associated with relatively high peri- and postoperative morbidity. Complications may result from infection or may relate to the surgical procedure (anastomotic leak, hemorrhage) (Table 5.12).

Leaks

Leaks may occur at any anastomotic site. The imaging modality of choice is contrast-enhanced CT.

- Smaller collections are usually located in the left subphrenic space (negative abdominal pressure during respiration).
- Leakage from the duodenal stump is likely to produce complications because the escaping pancreatic and biliary fluid may incite a chemical peritonitis and infection. Fluid collections and abscesses are most commonly located in the right subhepatic space or at peripancreatic sites. Duodenal stump leaks should be surgically repaired!

After Pancreatic Surgery (Whipple Operation)

The most common surgical procedure on the pancreas, called the Kausch-Whipple operation (pancreaticoduodenectomy, PD), includes a duodenectomy, a partial or complete pancreatectomy, resection of the gastric antrum, and the resection of a short segment of jejunum in most cases (Fig. 5.29a). Gastrointestinal continuity is restored by:

- pancreaticojejunostomy (after partial resections)
- choledochojejunostomy
- gastrojejunostomy

When the pylorus is preserved (pylorus-preserving pancreaticoduodenectomy, PPPD), an anastomosis is created between the jejunum and the postpyloric duodenal stump (Fig. 5.29b).

Table 5.12 Complications after partial or total gastrectomy

- Intra-abdominal bleeding
- Mediastinal hematoma and hemothorax
- Wound infection
- Anastomotic leak with abscess formation (Fig. 5.28)
- Pancreatitis
- Afferent loop syndrome
- Mechanical obstruction (herniation, kinking, intussusception, or recurrent tumor)
Normal Postoperative Findings

Owing to the frequent delay of gastric emptying that occurs after pancreatic surgery and poor retrograde opacification with contrast medium, the proximal jejunal limb (Roux limb) is poorly visualized and the bilioenteric or pancreaticoenteric anastomosis is correspondingly difficult to evaluate. The proximal jejunal limb is often located in the gallbladder bed or porta hepatis after the operation and should not be mistaken for an abscess.

Practical Recommendation

The afferent limb may be mistaken at follow-up for an abscess or tumor unless the specifics of the operation are known. Small bowel is identified by the presence of valvulae conniventes. Oral contrast opacification of the afferent limb can be improved by the IV administration of 1 mg glucagon (see Fig. 5.31).

More than 80% of patients undergoing PD are found to have postoperative fluid collections in the pancreatic bed, Morison pouch, and right paracolic gutter. In most cases these collections are reabsorbed within a matter of days. Clinical suspicion of infection should be investigated by follow-up and by fine-needle aspiration if necessary.

Complications

Anastomotic Leaks

The pancreaticoenteric anastomosis has a particularly high complication rate (ca. 15%) in nonfibrotic pancreatic parenchyma (tumor surgery). A leak is evidenced by a change in the composition of the drainage material (lipase and amylase detection). Adequate drainage of the anastomotic site should significantly improve or relieve systemic symptoms. The placement of additional drains may be indicated. Reoperation and revision of the anastomosis are associated with a high risk of further leakage.

Leakage from a biliary-enteric anastomosis is confirmed by the presence of bile in the drainage material (Fig. 5.30).

Abscesses can be positively identified only by detecting small air bubbles within the lesion. Basically any fluid collection may become superinfected (suspicious clinical signs, needle aspiration). Abscesses may form at various sites: subphrenic, intrahepatic, in the cul-de-sac, in the gallbladder bed (the gallbladder is usually removed!), or in the lesser sac. It is common to find multiple abscesses that do not communicate with one another and thus require separate drainage.

Practical Recommendation

Helpful criteria for distinguishing a fluid-filled loop of jejunum from an abscess are oral contrast opacification (Fig. 5.31, not always successful), air–fluid levels, IV contrast administration to detect bowel wall enhancement, and the identification of

Fig. 5.29a, b Types of reconstruction after pancreatic resections.

a A Whipple pancreaticoduodenectomy with resection of the pancreatic head, antrum, and duodenum is followed by the creation of three anastomoses: a gastrojejunostomy, a pancreaticojejunostomy, and a choledochojjunostomy.

b In a pylorus-preserving pancreaticoduodenectomy (PPPD), the pylorus and a short segment of duodenum are preserved.

Fig. 5.30 Leakage from a pancreaticoenteric anastomosis after partial pancreatectomy and drain insertion.
Coronary vessels are visible within the thymic shadow much as they are in the retrocardiac space. On the ultrasound scan the thymus presents a characteristic homogeneous echo pattern with multiple interspersed “white dots” that resemble snowflakes.

The thymus is relatively large through 4 years of age (with considerable anatomic variation) and undergoes a steady involution after 9 years. Even if the thymus appears large on radiographs and covers the cardiac border and hila, normally it will never compress or displace mediastinal structures. This serves to distinguish a normal thymus from pathologic thymic dysplasia or a mediastinal tumor, which may become symptomatic if they compress or displace vessels or respiratory passages.

Cardiac size. Measurements for estimating cardiac size, like those performed in adults, are much less useful in children due to variables introduced by the thymus and variations in inspiratory position (a cardiothoracic ratio < 0.65 can serve as a guideline).

**Practical Recommendation**

In doubtful cases the lateral radiograph can be used to estimate cardiac size: The posterior cardiac border should not extend past a line drawn tangentially to the anterior tracheal border (Swischuk line). Echocardiography can be used for further cardiac evaluation.

### During Mechanical Ventilation

The tip of the endotracheal tube should be above the carina at the level of the T2 vertebral body. The chin and head position should be noted during imaging: When the head is flexed, the tip of the tube is about 1 cm above the carina. Extending the head or tilting it to one side raises the tip to approximately the level of T1 or the head of the clavicle.

In infants with normal lung expansion during mechanical ventilation (e.g., high-frequency oscillatory ventilation), the right hemidiaphragm is projected between the posterior portions of the eighth and ninth ribs.

---

**Catheter Position: Normal Findings and Malposition**

The anatomy of the fetal circulation is shown schematically in Fig. 6.3. The umbilical artery catheter (UAC) initially descends into the lesser pelvis. It enters the systemic circulation through the internal iliac artery or common iliac artery and runs toward the aorta. Its tip may be positioned above the aortic bifurcation, distal to the origin of the renal arteries (“low position” at the L3/L4 level), or at the level of the midthoracic aorta above the origins of the visceral arteries (“high position” at the T7/T8 level). The catheter tip should not be located between

---

**Fig. 6.3 Anatomy of the fetal circulation.**
The umbilical vein arises from the placenta and opens into the inferior vena cava via the ductus venosus. The umbilical artery arises from the internal iliac artery and runs back along the bladder to the placenta. Because of this arrangement, an umbilical arterial catheter (UAC) first descends into the lesser pelvis whereas an umbilical venous catheter (UVC) runs cephalad to the liver.

1 Placenta
2 Bladder
3 Right lobe of liver
4 Left lobe of liver
5 Right lung
6 Left lung
7 Umbilical artery
8 Iliac artery
9 Aorta
10 Umbilical vein
11 Iliac vein
12 Ductus venosus
13 Inferior vena cava
14 Right ventricle
15 Left ventricle
16 Right atrium
17 Left atrium
18 Superior vena cava
the origins of the visceral or renal arteries ("no position" between T10 and L3 levels) (Fig. 6.4).

The umbilical vein catheter (UVC) runs directly upward through the ductus venosus and left portal venous system into the inferior vena cava. The tip should be just below the diaphragm, occupying a level that is cranial to the level of the liver veins and caudal to the right atrium (Fig. 6.4). The catheter tip should not be intrahepatic, as it might cause liver injury (Fig. 6.5).

Irrespective of whether the central venous catheter has been introduced through the inferior or superior vena cava, the tip should be just outside the right atrium. The same applies to the very thin peripheral venous catheters (silastic catheters), which are difficult to locate radiographically because of their small diameter. Their tip should also be outside the right atrium.

The tip of the gastric tube should be below the diaphragm!

**Fig. 6.4** Normal catheter position in a newborn.
The umbilical artery catheter (UAC, arrowheads) first dips into the lesser pelvis. Its tip is placed at the level of the T8 vertebra (high position). The umbilical vein catheter (UVC, arrows) runs directly cephalad with its tip just below the diaphragm.

**Fig. 6.5 a–c** Malpositioned catheters.
a The UAC is positioned too high (T5 level).
b The UVC is in the portal vein. The endotracheal tube is in the right main bronchus, causing atelectasis of the left lung. The gastric tube and UAC are correctly positioned.
c The UVC is in the portal vein, and the UAC is correctly positioned. The gastric tube is looped in the stomach, and the endotracheal tube is correctly positioned.